TENAX

Technical Reference GRID-TE-5

PULLOUT TESTS OF TENAX GEOGRIDS

PULLOUT TESTING OF GEOGRIDS

TESTING PROGRAM

The testing program has been designed to evaluate the different geogrid/soil interlock capacity by means of pullout testing. Several pullout tests were conducted on two types of biaxial polypropylene geogrids currently marketed in the USA: a multilayer type of geogrid and a conventional single layer geogrid.

The properties of the products tested are listed in Table 1.

Table 1 - Properties of the geogrids included in the pullout program
(From Published Data)

Product Name	Numbers of Layers	Unit Weight, g/m2	Tensile Strength, kN/m	Tensile Strength @ 2% Strain, kN/m	Junction Strength, kN/m
Tenax MS220	2	240	13.5 x 20.5	4.1 x 6.0	12.2 x 18.5
Tenax MS330	3	360	20.0 x 30.7	6.1 x 9.0	18.0 x 27.7
Tenax MS500	5	315	22.0 x 35.0	6.0 x 10.0	19.8 x 31.5
Tensar SS1 (BX1100)	1	200	12.4 x 12.4	4.0 x 4.0	11.1 x 11.1
Tensar SS2 (BX1200)	1	300	17.5 x 17.5	5.4 x 5.4	15.7 x 15.7

Prior to performance of the pullout tests, the geogrids were visually inspected and tested in agreement with GRI-GG1:87 "Single Rib Tensile Test Method" to assure their compliance with the above properties. All of the products met the property requirements.

The pullout test were conducted on granular material, Sand EN196:1. The properties related to this aggregate, including gradation curve, proctor curve and direct shear curve, are presented in Appendix 1.

TEST PROCEDURE

For each pullout test, the following procedure was applied:

- The soil was placed in the lower half of the box thus to obtain a compacted minimum thickness of 115 mm. The pullout tests were conducted with the sand at a relative dry density of 95% of the proctor value and at a moisture content of 2%. The tests were carried out with an actual soil density of 17.5 kN/m^3. The above values of density and moisture content were constantly controlled during the preparation of the tests;

- A fresh specimen was randomly cut from the sample rolls of the geogrid material. The dimensions of the specimens were about 400 mm wide by 1000 mm long. Each specimen was prepared in such a way that the transverse direction ribs were parallel to the pullout direction. The specimens were then inserted into the metal sleeves of the pullout device and placed flat upon the compacted soil. The outer portion of the geogrid specimens were clamped into a flat type of clamp and serrated by bolts. A layer of rubber was used to prevent mechanical damage and cuts to the tested specimens. Care was taken to assure, by means of this clamp, a uniform distribution of load on all the ribs of the specimens. No failures in the clamps were recorded on all the specimens tested;

- Three "tell-tail" harmonic steel wires were connected along the longitudinal portion of the specimen at the following positions:
    - at the pullout box end,
    - at the pullout box center,
    - 20 mm far from the edge of the metal sleeves, as shown by the arrows in Figure 1.

  The displacements of these metal wires were monitored during the test every 3 min to determine the distribution of loading and the pullout rate along the specimen length;

- The upper layer of soil was then placed and compacted in the remaining 115 mm the pullout box using an hand tamping method;

- The normal confining pressure was applied through a hydraulic piston controlled by a digital close-loop controller system. A 20 mm foamed rubber layer was used to uniformly distribute the load from a metal plate and the soil;

- Once the normal load was applied, a second hydraulic actuator was started to pull the geogrid layer out from the box at a rate of 1 mm/min. The test was continued until constant or decreasing pullout force was obtained and a minimum of about 50 mm travel was recorded;

The test data, including the vertical load and settlement, the pullout force and displacement, were collected at a frequency of 1 Hz. Typical applied normal stresses were 10, 20, 30 and 40 kPa.

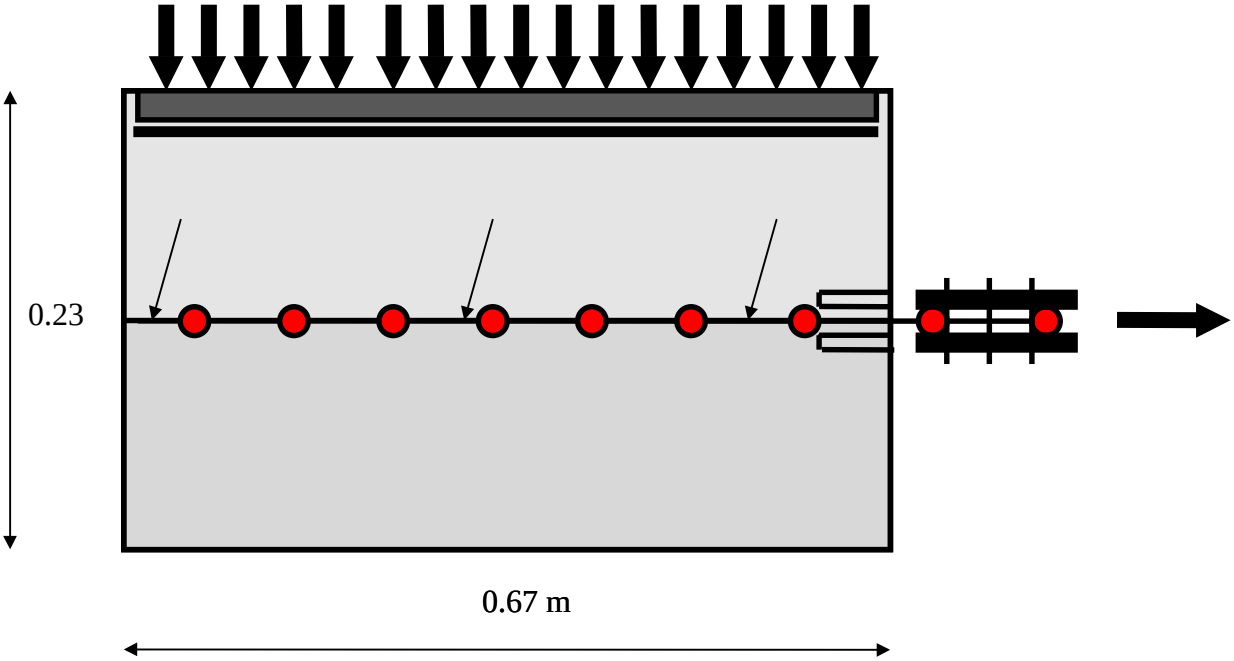


Figure 1: Schematic view of the pullout apparatus. Not to scale

TEST RESULTS

A summary table of the pullout test results is presented in Appendix 2.
In addition, for all series of tests, the following curves are given in Appendix 3:

- Pullout Strength versus Displacement curve (actual data);
- Pullout Strength versus Displacement curve (polynomial regression line);
- Pullout Strength versus Normal Stress curve;
- Pullout Coefficient of Interaction versus Normal Stress curve;
- Comparisons between the Pullout Coefficients of Interaction of different geogrids.

The Pullout Coefficient of Interaction (f_{po}) was calculated at peak conditions using the equation given below:

$$f_{po} = \frac{F}{2 * A * \sigma_n * (\tan \phi + c)} \qquad (1)$$

where:

- F = Maximum Pullout Load, (kN);
- f_{po} = Pullout Coefficient of Interactions, (-);
- A = Initial Embedded Specimen Area, m^2;
- σ_n = Applied Normal Stress, kPa;
- ϕ = Residual Soil Friction Angle, deg;
- c = Soil Cohesion (neglected in this case), kPa.

It is noted that both pullout and tensile failure modes were recorded during the tests. The tensile failure modes were recorded especially at the highest normal stresses (at 40 kPa normal stress).

The tensile failure mode was identified by either noticing the tensile failure of the geogrid ribs or by analysing the movements and the speed of travel of the “tell-tail” wire displacement sensors located along the length of the geogrid specimens.

In Table 2, the type of failure mode is reported together with the actual pullout force recorded.

APPENDIX 1

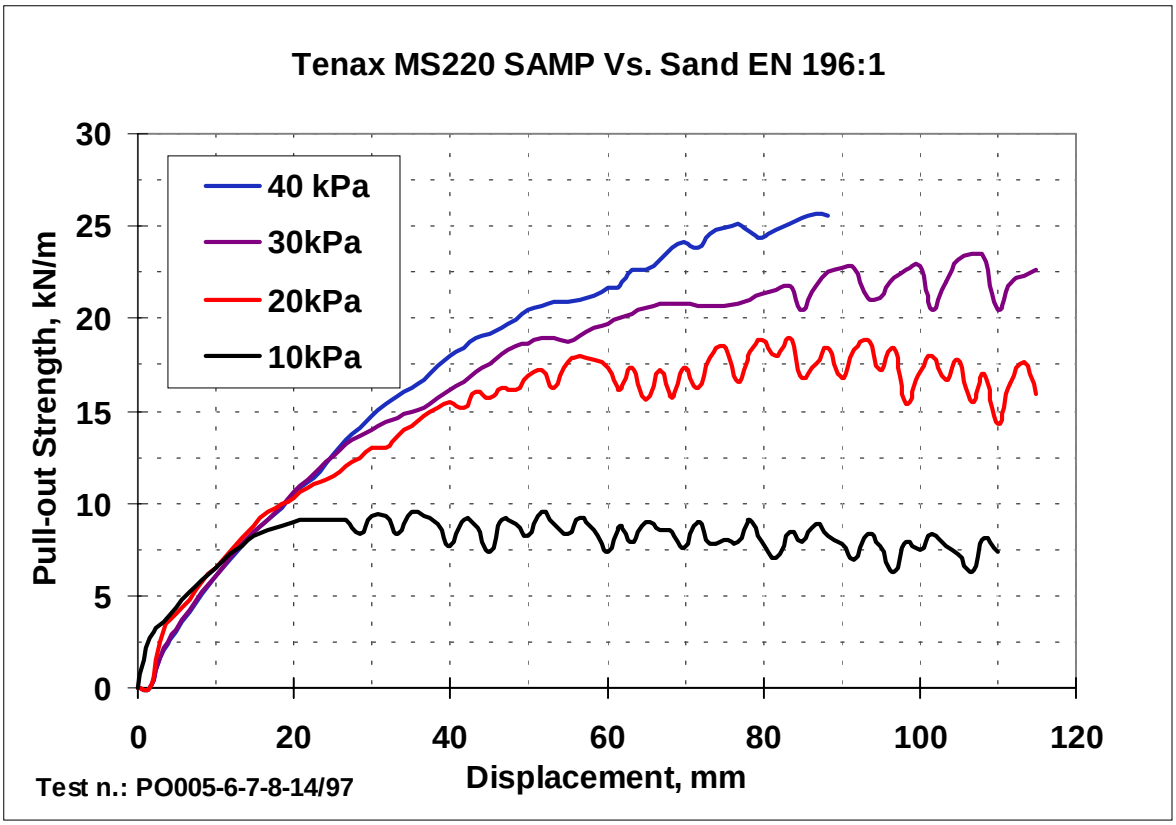
APPENDIX 2

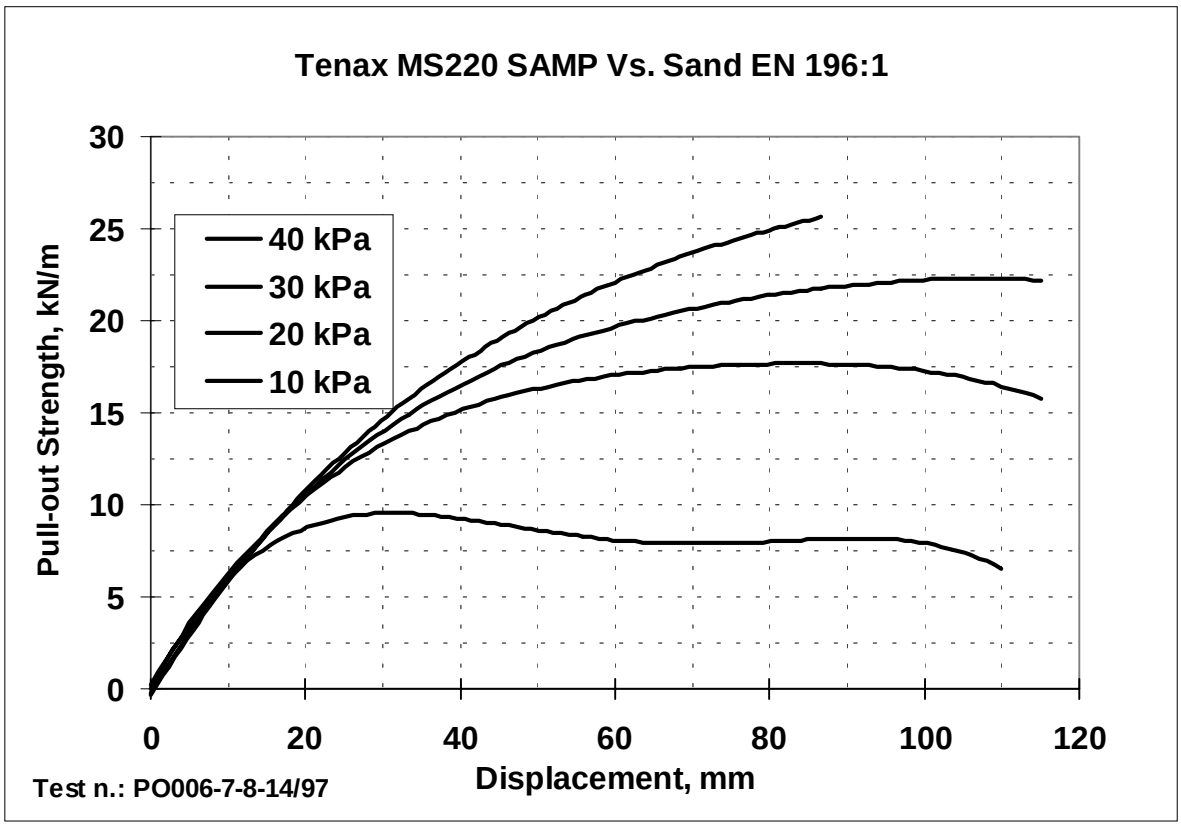
Table 2: Summary table of the pullout test results and test conditions

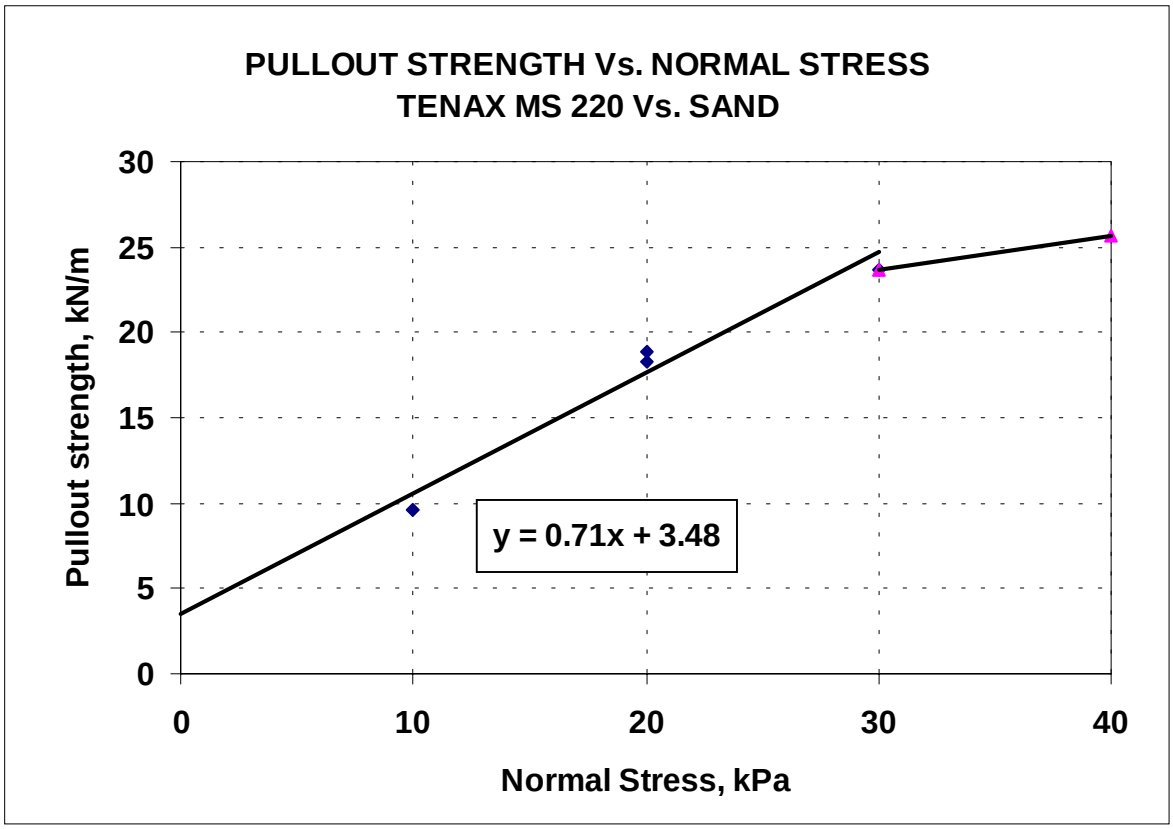
PRODUCT NAME		**TENAX MS220**	**TENAX MS220**	**TENAX MS220**	**TENAX MS220**	**TENAX MS220**	**TENSAR SS1**	**TENSAR SS1**	**TENSAR SS1**	**TENSAR SS1**
Test Direction		TD	TD	TD	TD	TD	TD	TD	TD	TD
Normal stress	kPa	40	30	20	20	10	40	30	20	10
test n.		6	14	5	8	7	11	27	10	12
Max. Pullout Strength	kN/m	25.72	23.72	18.27	18.91	9.58	19.50	17.10	13.76	6.70
Max. Pullout Stress	kPa	43.96	40.55	31.24	32.33	16.38	33.30	29.20	23.52	11.40
Failure type		Tension	Tension	Pullout	Pullout	Pullout	Tension	Tension	Pullout	Pullout
ϕ soil	deg	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
Specimen Length, L	m	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585
Pullout Interaction Factor	fpo	0.70	0.87	1.00	1.03	1.05	0.53	0.62	0.75	0.73

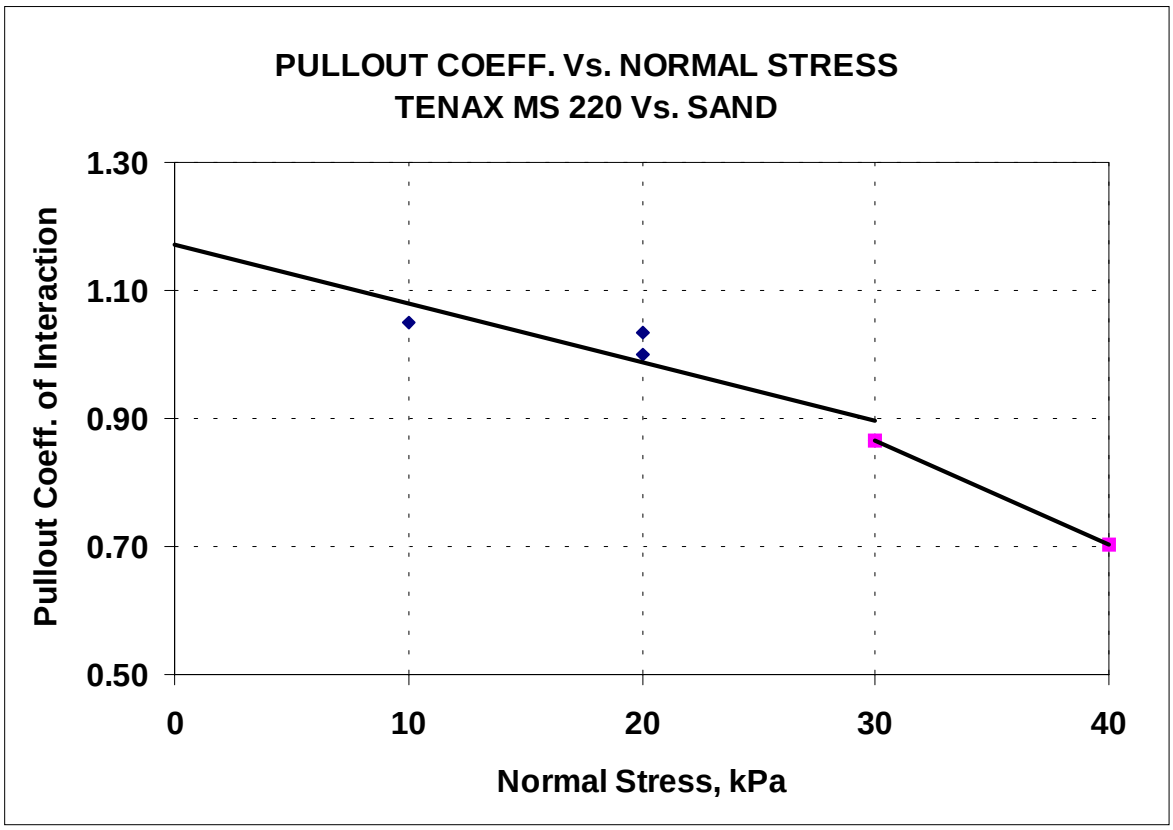
PRODUCT NAME		**TENAX MS330**	**TENAX MS330**	**TENAX MS330**	**TENAX MS500**	**TENAX MS500**	**TENAX MS500**	**TENSAR SS2**	**TENSAR SS2**	**TENSAR SS2**
Test direction		TD	TD	TD	TD	TD	TD	TD	TD	TD
Normal stress	kPa	30	20	10	30	20	10	30	20	10
test n.		17	15	16	23	21	22	20	18	19
Max. Pullout Strength	kN/m	24.93	18.71	10.53	26.14	17.70	10.18	22.00	14.90	7.60
Max. Pullout Stress	kPa	42.62	31.99	17.99	44.69	30.26	17.40	28.30	25.50	13.00
Failure type		Pullout	Pullout	Pullout	Pullout	Pullout	Pullout	Pullout	Pullout	Pullout
ϕ soil	deg	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00	38.00
Specimen Length, L	m	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585	0.585
Pullout Interaction Factor	fpo	0.91	1.02	1.15	0.95	0.97	1.11	0.80	0.82	0.83

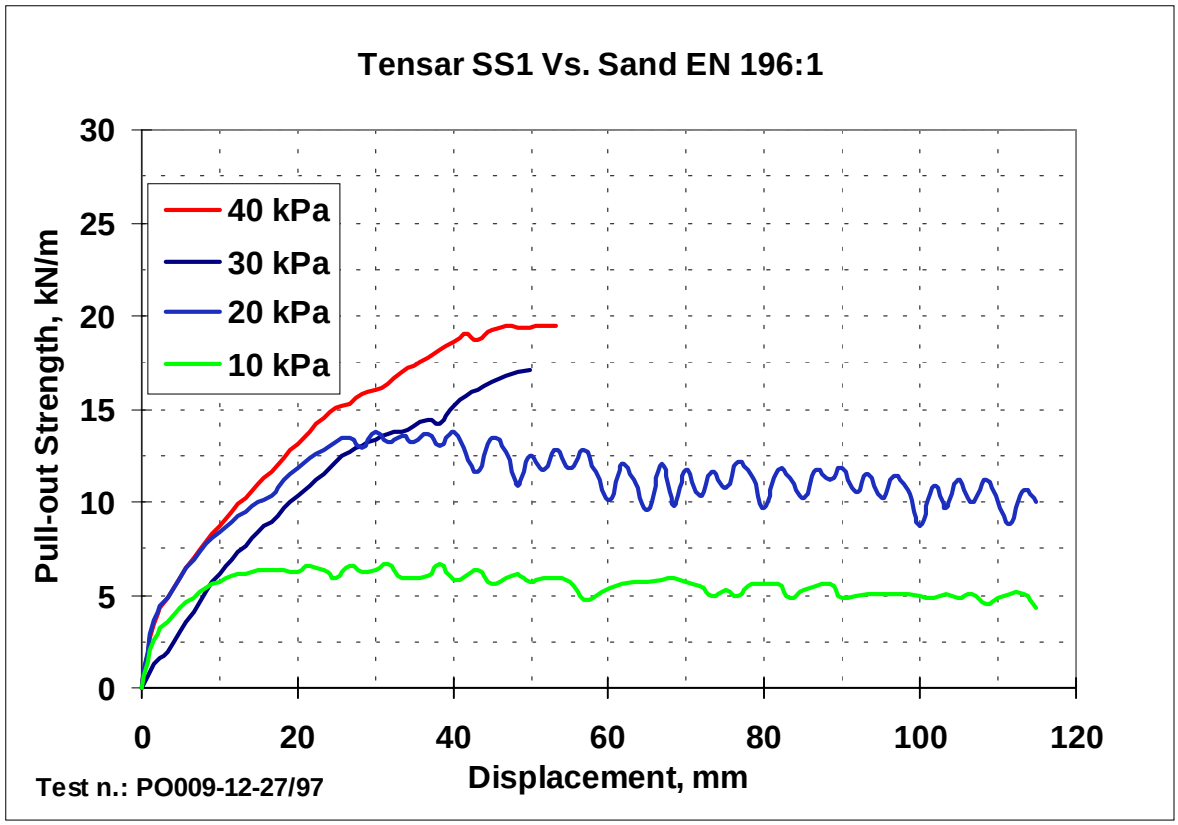
APPENDIX 3

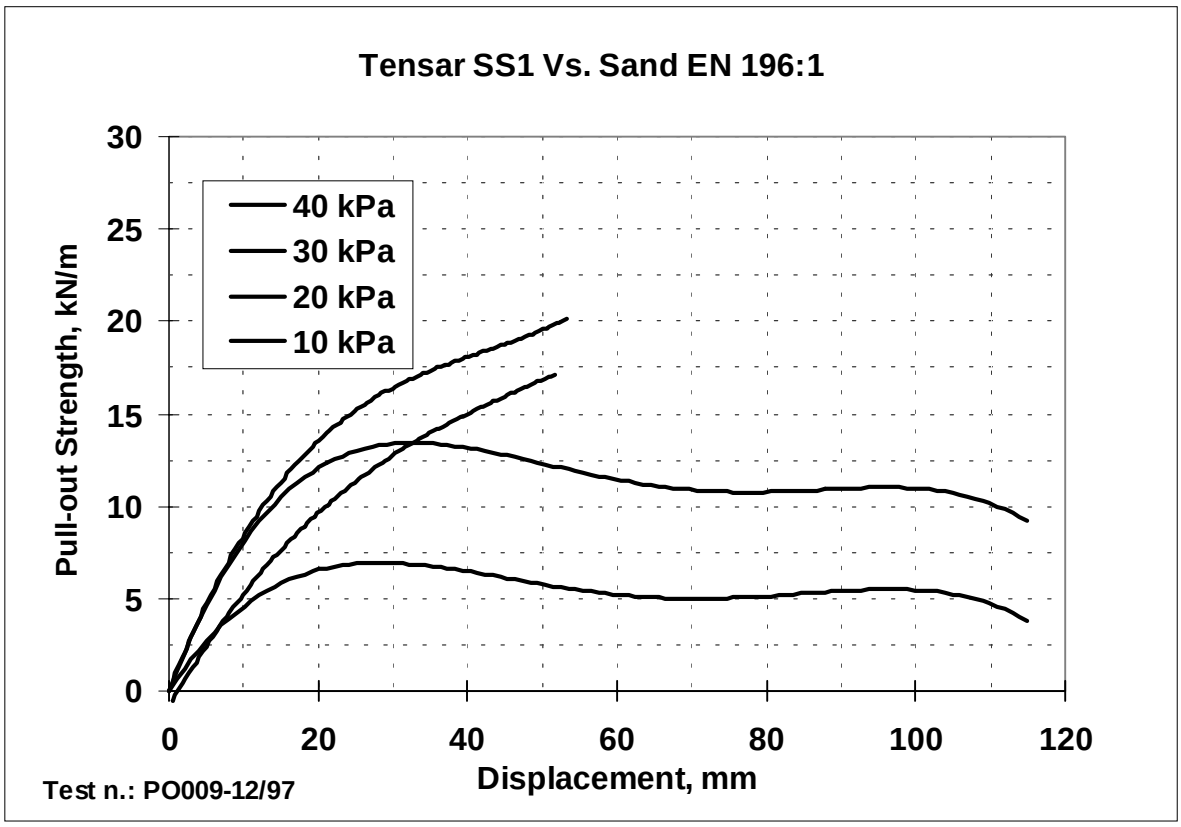

Tenax MS220 SAMP Vs. Sand EN 196:1
Pull-out Strength, kN/m
Displacement, mm
40 kPa
30kPa
20kPa
10kPa
0
5
10
15
20
25
30
0
20
40
60
80
100
120
Test n.: PO005-6-7-8-14/97

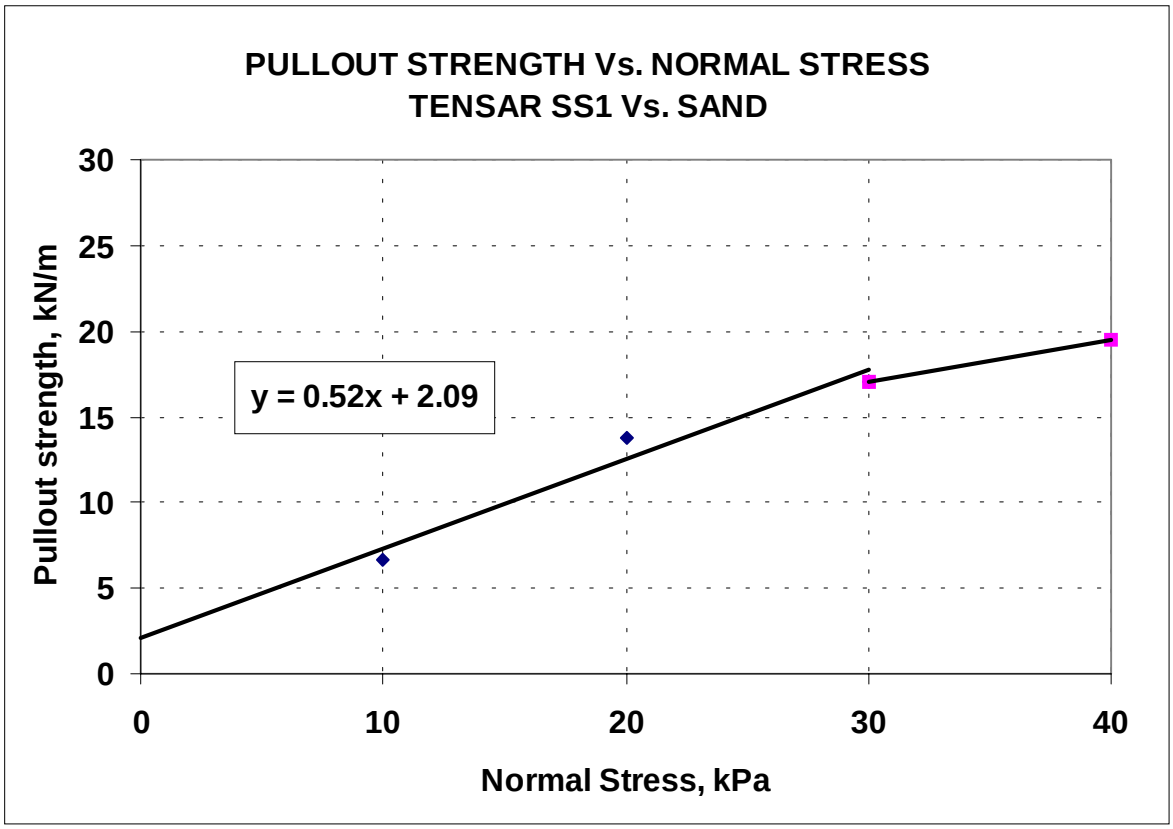

Tenax MS220 SAMP Vs. Sand EN 196:1
Pull-out Strength, kN/m
Displacement, mm
40 kPa
30 kPa
20 kPa
10 kPa
0
5
10
15
20
25
30
0
20
40
60
80
100
120
Test n.: PO006-7-8-14/97

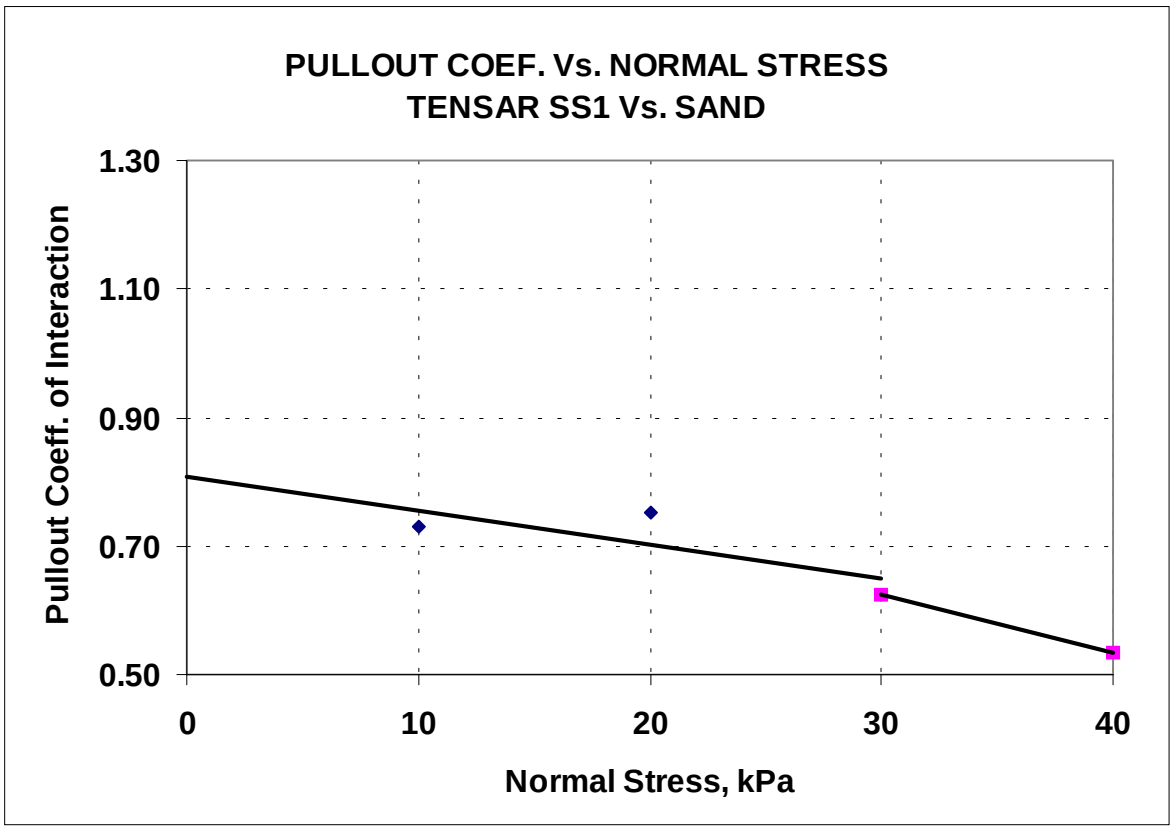

PULLOUT STRENGTH Vs. NORMAL STRESS
TENAX MS 220 Vs. SAND
Pullout strength, kN/m
30
25
20
15
10
5
0
y = 0.71x + 3.48
0
10
20
30
40
Normal Stress, kPa

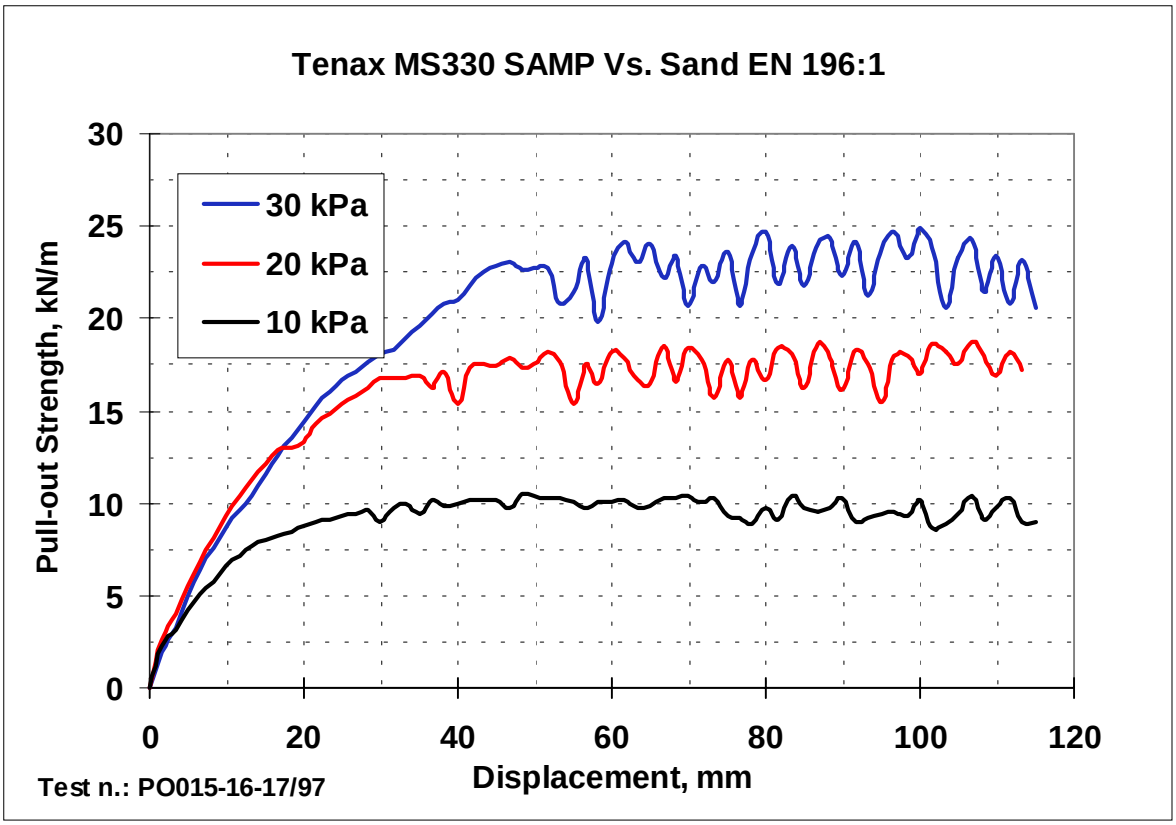

PULLOUT COEFF. Vs. NORMAL STRESS
TENAX MS 220 Vs. SAND
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
40
Normal Stress, kPa

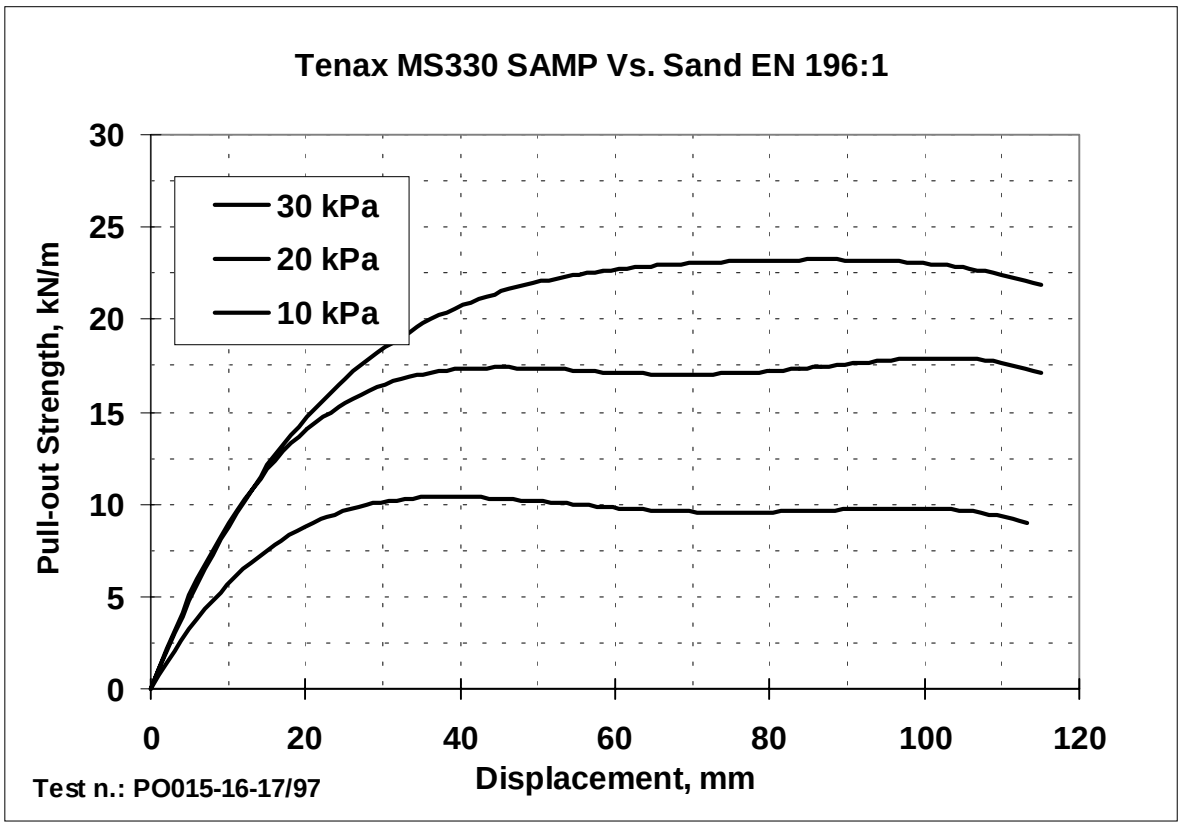

Tensar SS1 Vs. Sand EN 196:1
Pull-out Strength, kN/m
Displacement, mm
40 kPa
30 kPa
20 kPa
10 kPa
0
5
10
15
20
25
30
0
20
40
60
80
100
120
Test n.: PO009-12-27/97

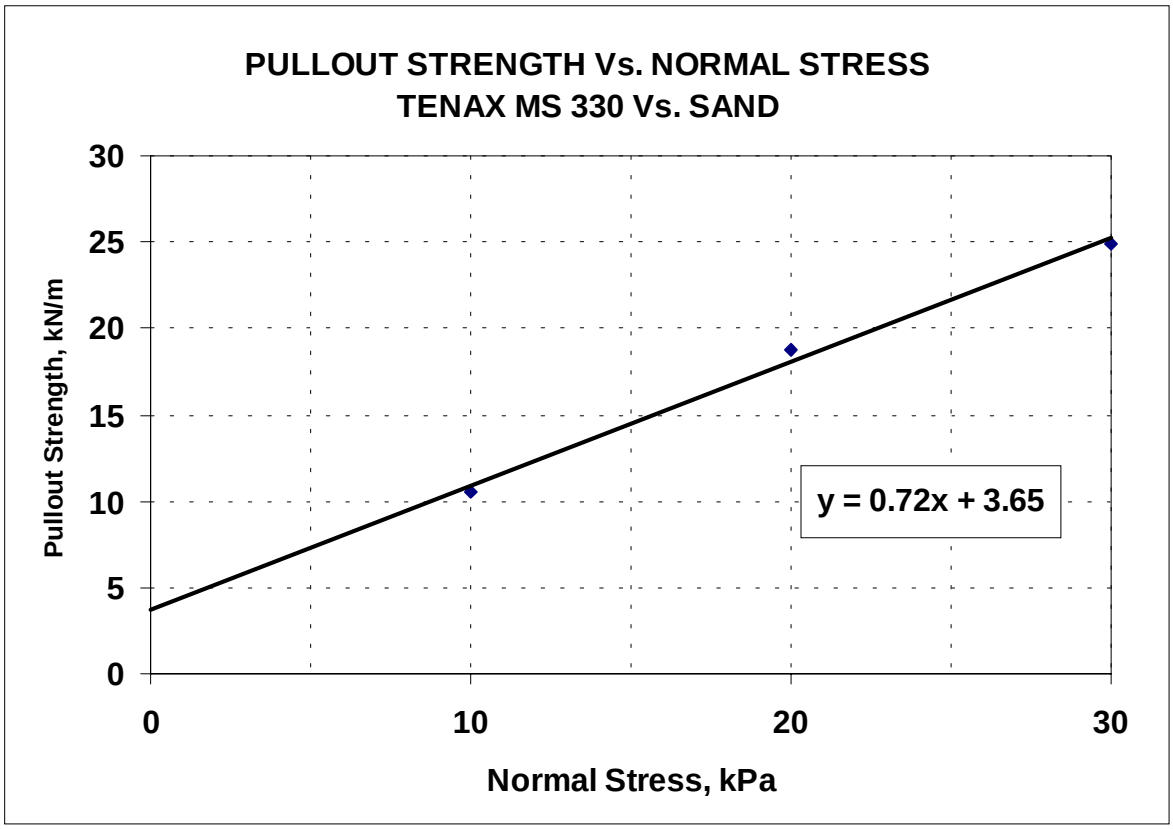

Tensar SS1 Vs. Sand EN 196:1
Pull-out Strength, kN/m
Displacement, mm
40 kPa
30 kPa
20 kPa
10 kPa
0
5
10
15
20
25
30
0
20
40
60
80
100
120
Test n.: PO009-12/97

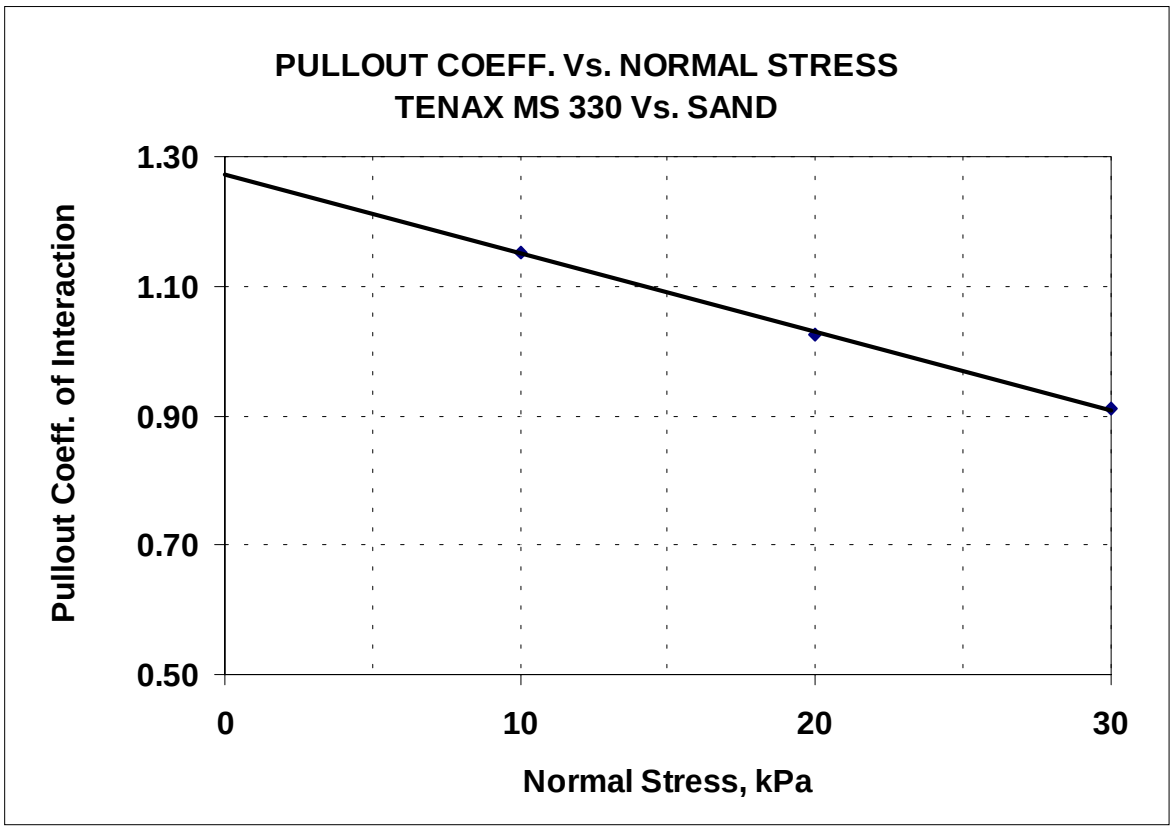

PULLOUT STRENGTH Vs. NORMAL STRESS
TENSAR SS1 Vs. SAND
Pullout strength, kN/m
30
25
20
15
10
5
0
y = 0.52x + 2.09
0
10
20
30
40
Normal Stress, kPa

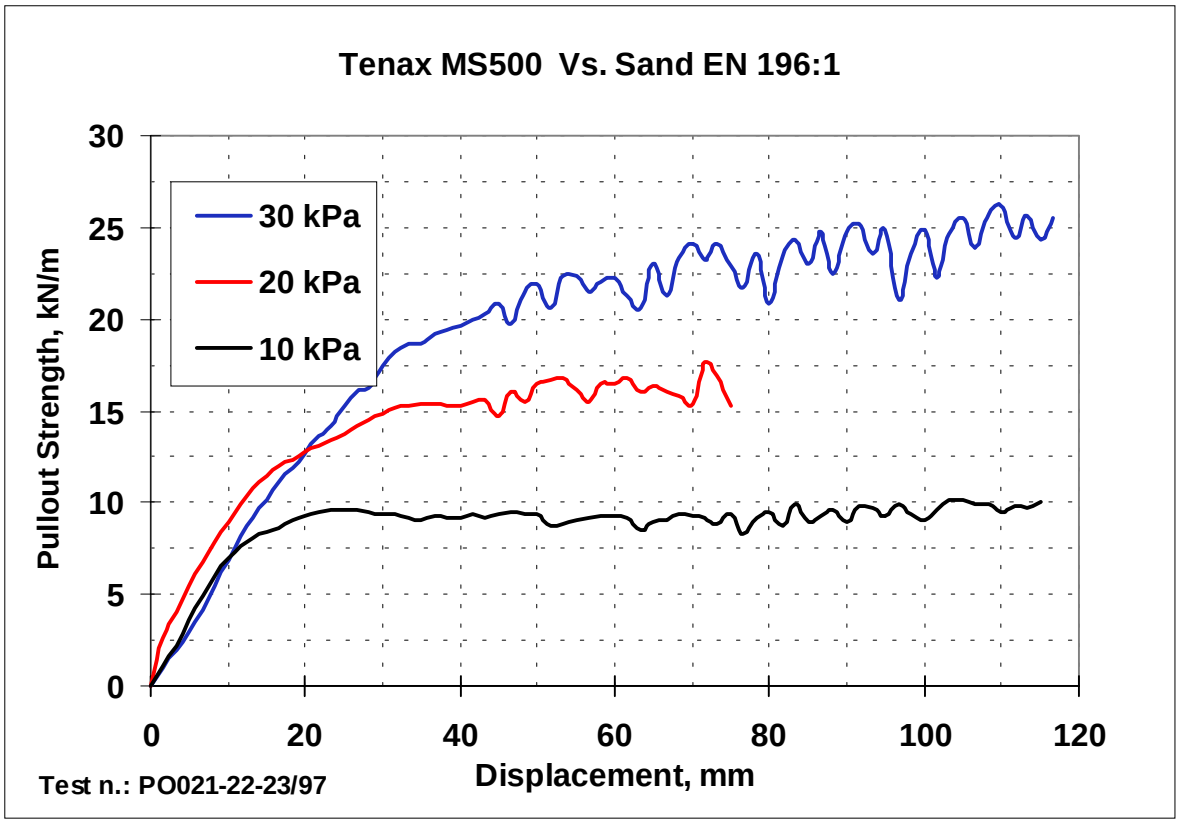

PULLOUT COEF. Vs. NORMAL STRESS
TENSAR SS1 Vs. SAND
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
40
Normal Stress, kPa

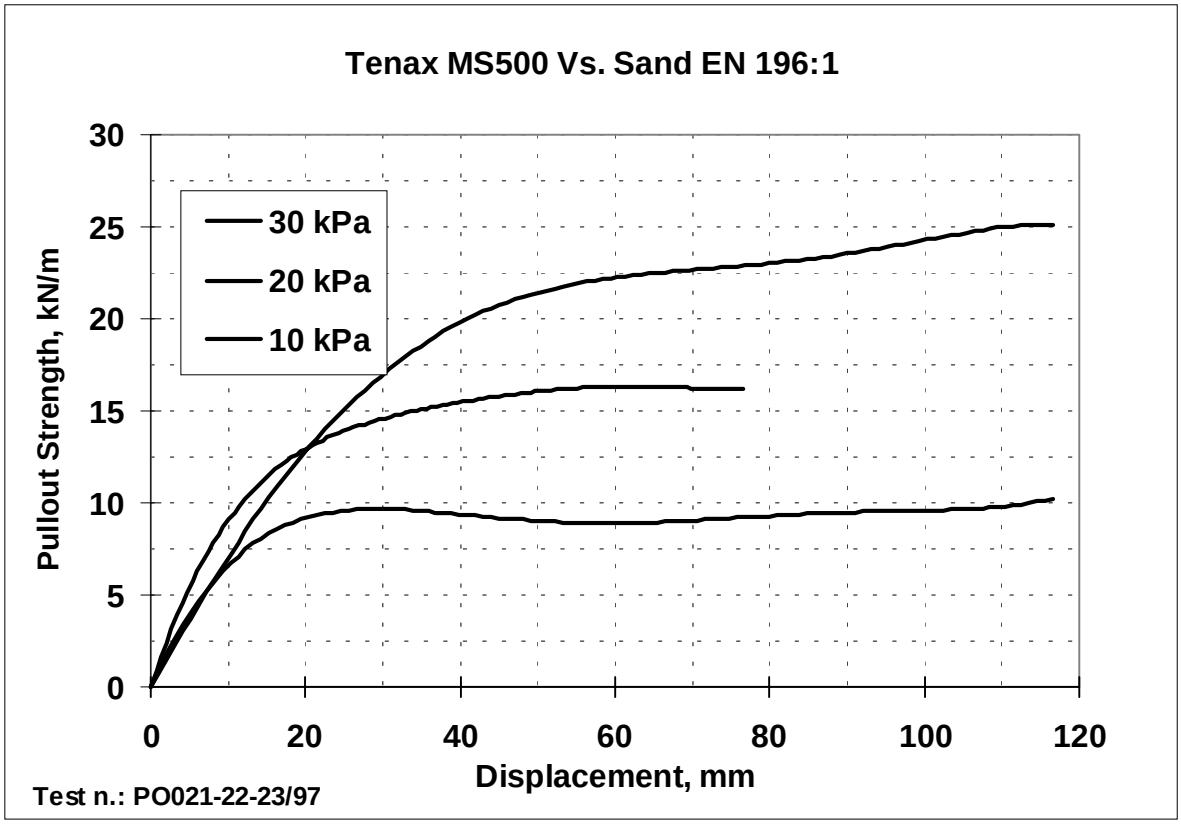

Tenax MS330 SAMP Vs. Sand EN 196:1
Pull-out Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO015-16-17/97

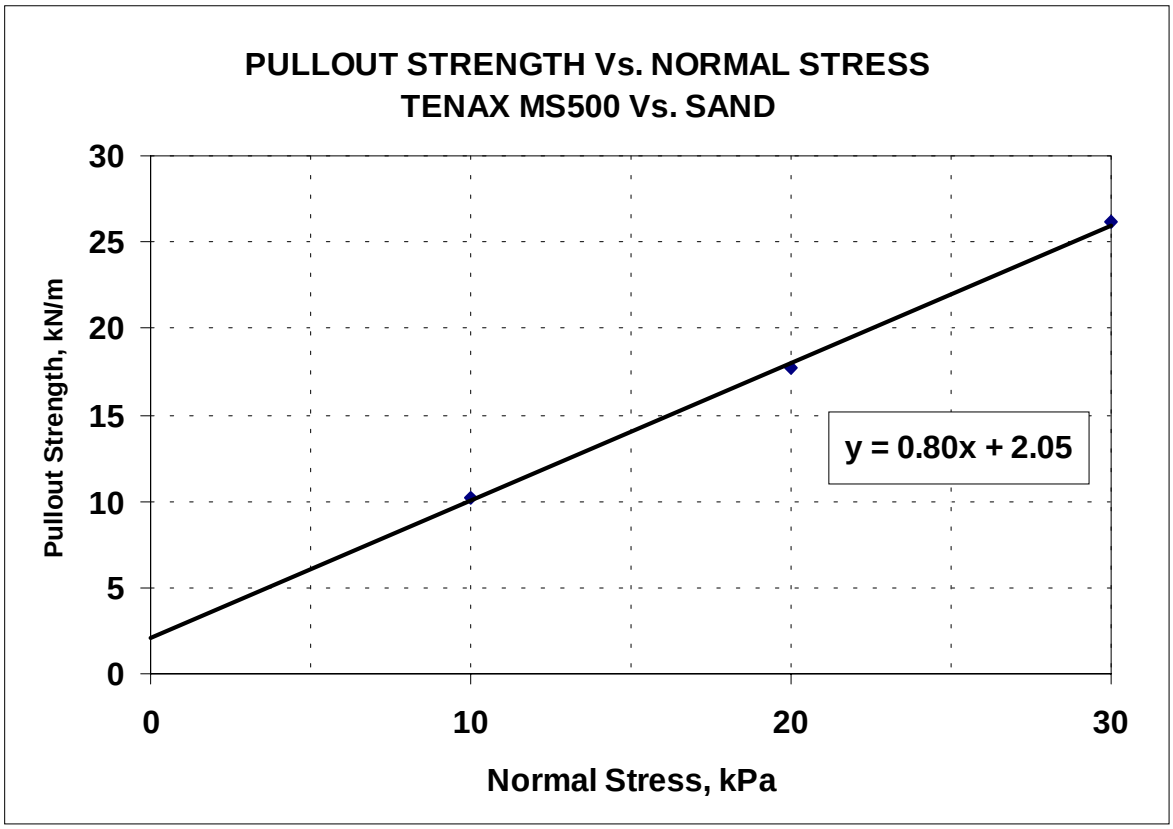

Tenax MS330 SAMP Vs. Sand EN 196:1
Pull-out Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO015-16-17/97

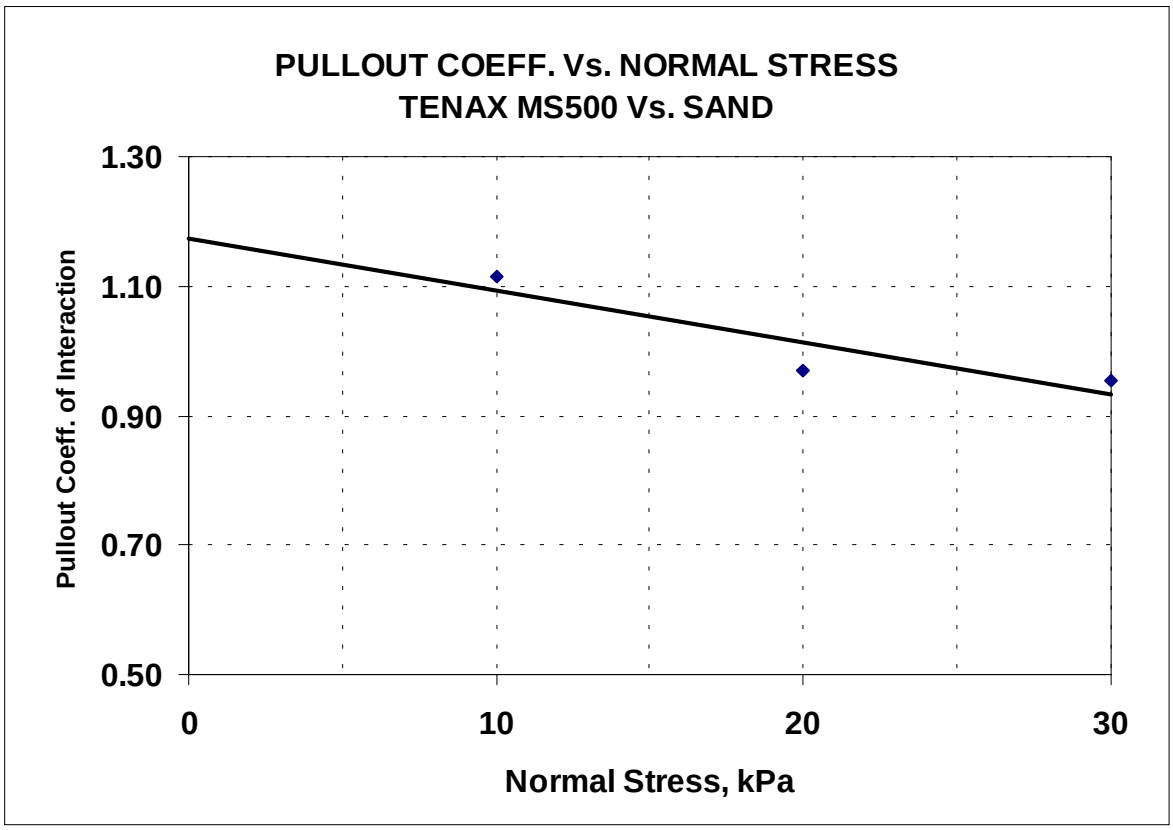

PULLOUT STRENGTH Vs. NORMAL STRESS
TENAX MS 330 Vs. SAND
Pullout Strength, kN/m
30
25
20
15
10
5
0
0
10
20
30
Normal Stress, kPa
y = 0.72x + 3.65

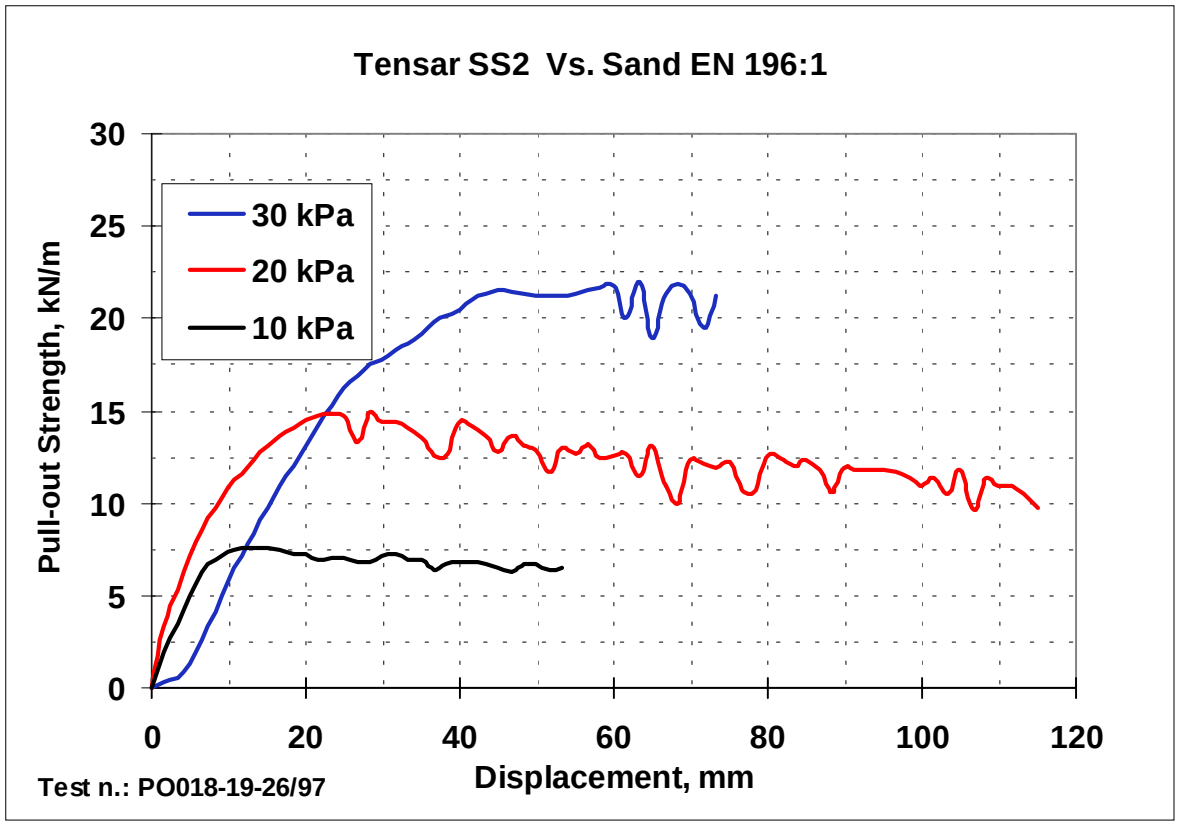

PULLOUT COEFF. Vs. NORMAL STRESS
TENAX MS 330 Vs. SAND
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
Normal Stress, kPa

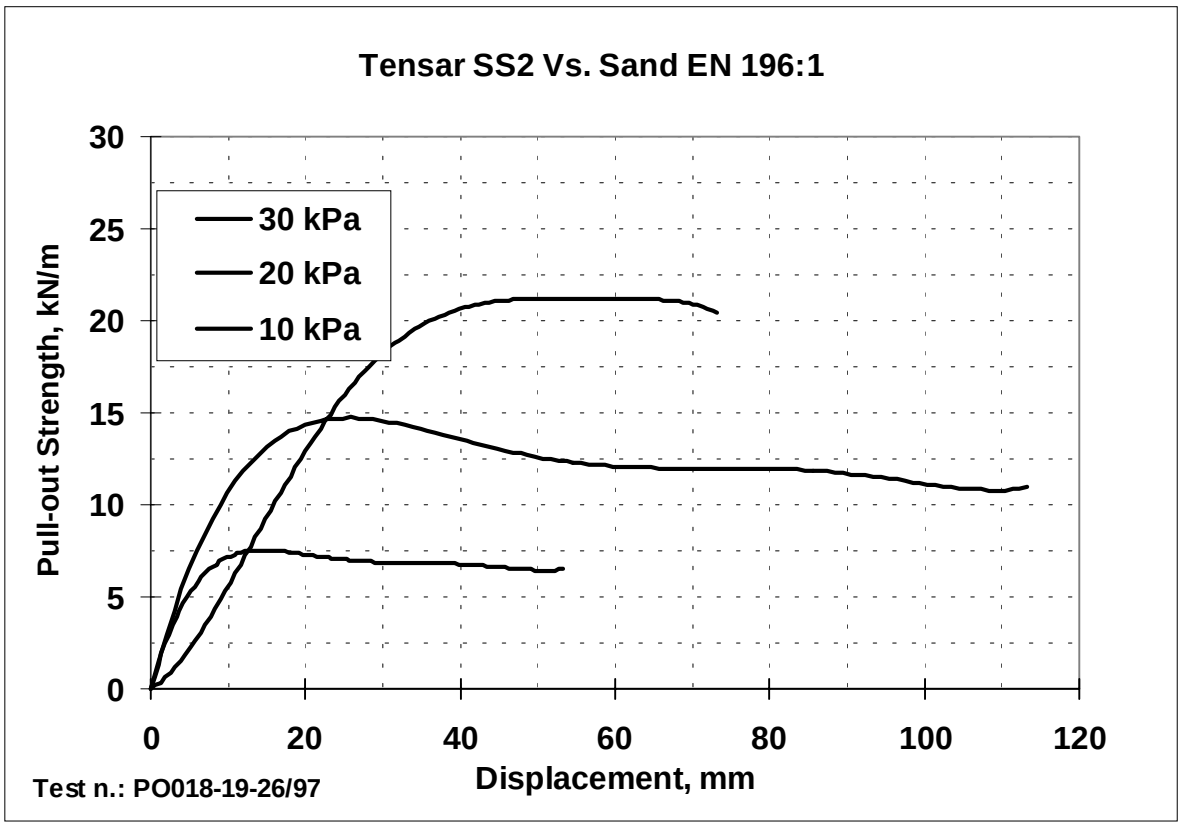

Tenax MS500 Vs. Sand EN 196:1
Pullout Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO021-22-23/97

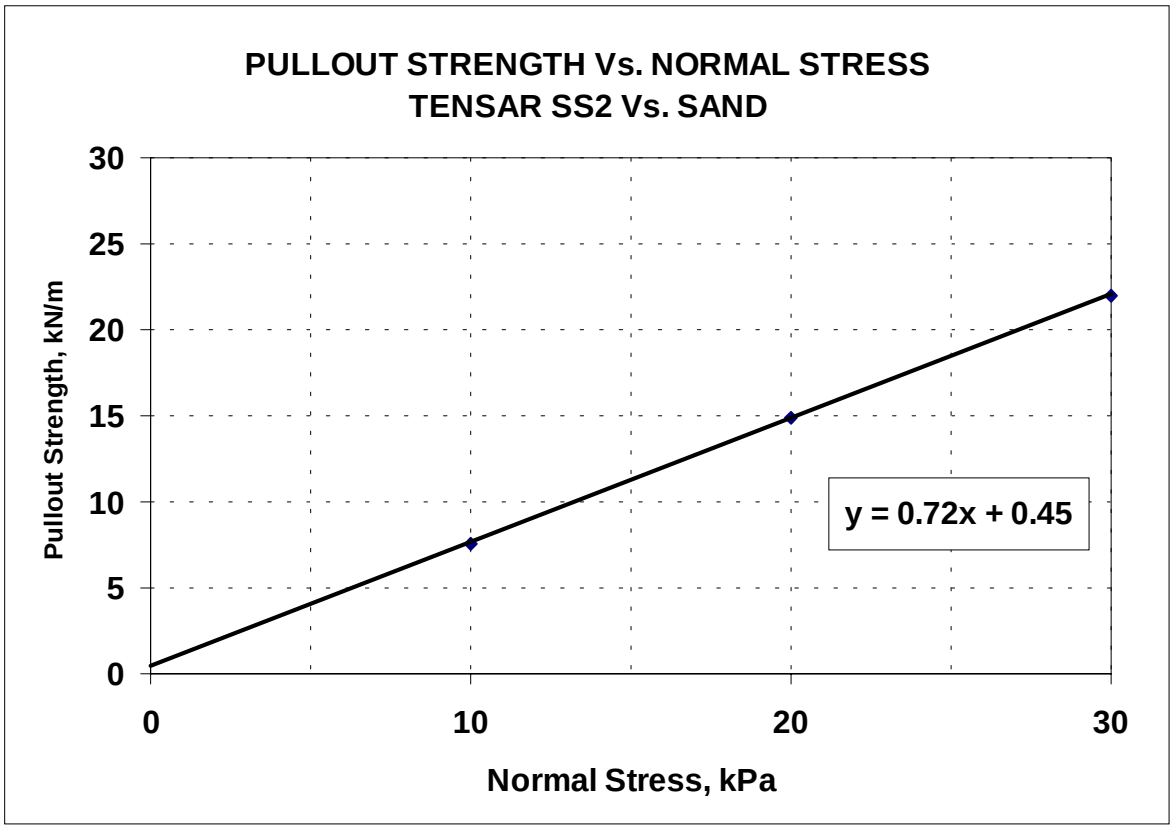

Tenax MS500 Vs. Sand EN 196:1
Pullout Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO021-22-23/97

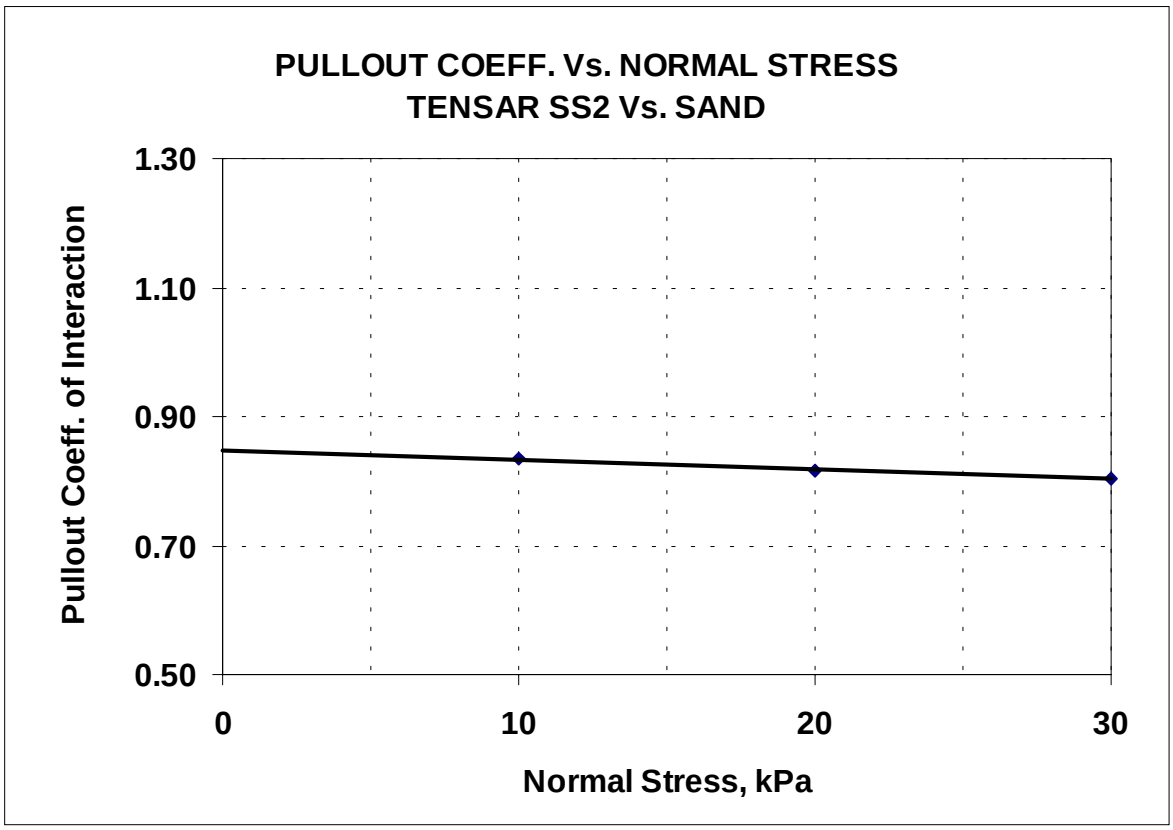

PULLOUT STRENGTH Vs. NORMAL STRESS
TENAX MS500 Vs. SAND
Pullout Strength, kN/m
30
25
20
15
10
5
0
0
10
20
30
Normal Stress, kPa
y = 0.80x + 2.05


PULLOUT COEFF. Vs. NORMAL STRESS
TENAX MS500 Vs. SAND
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
Normal Stress, kPa

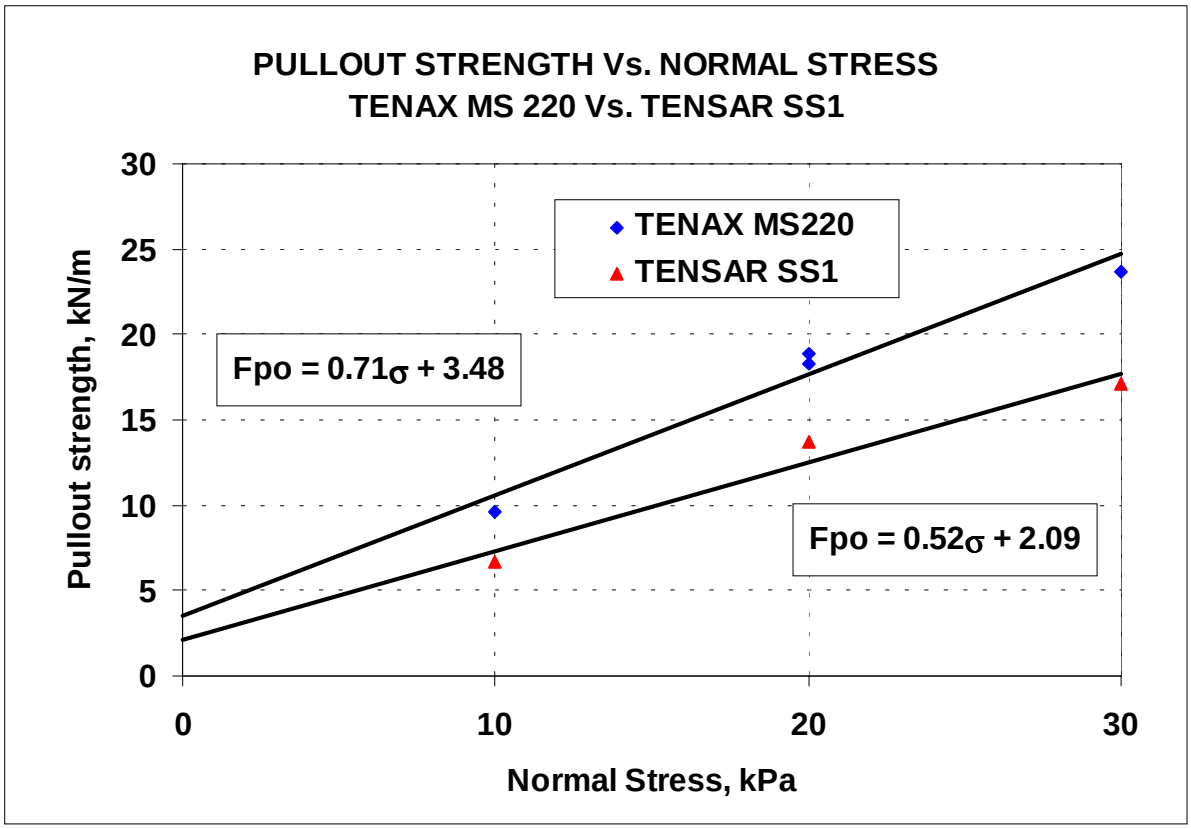

Tensar SS2 Vs. Sand EN 196:1
Pull-out Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO018-19-26/97

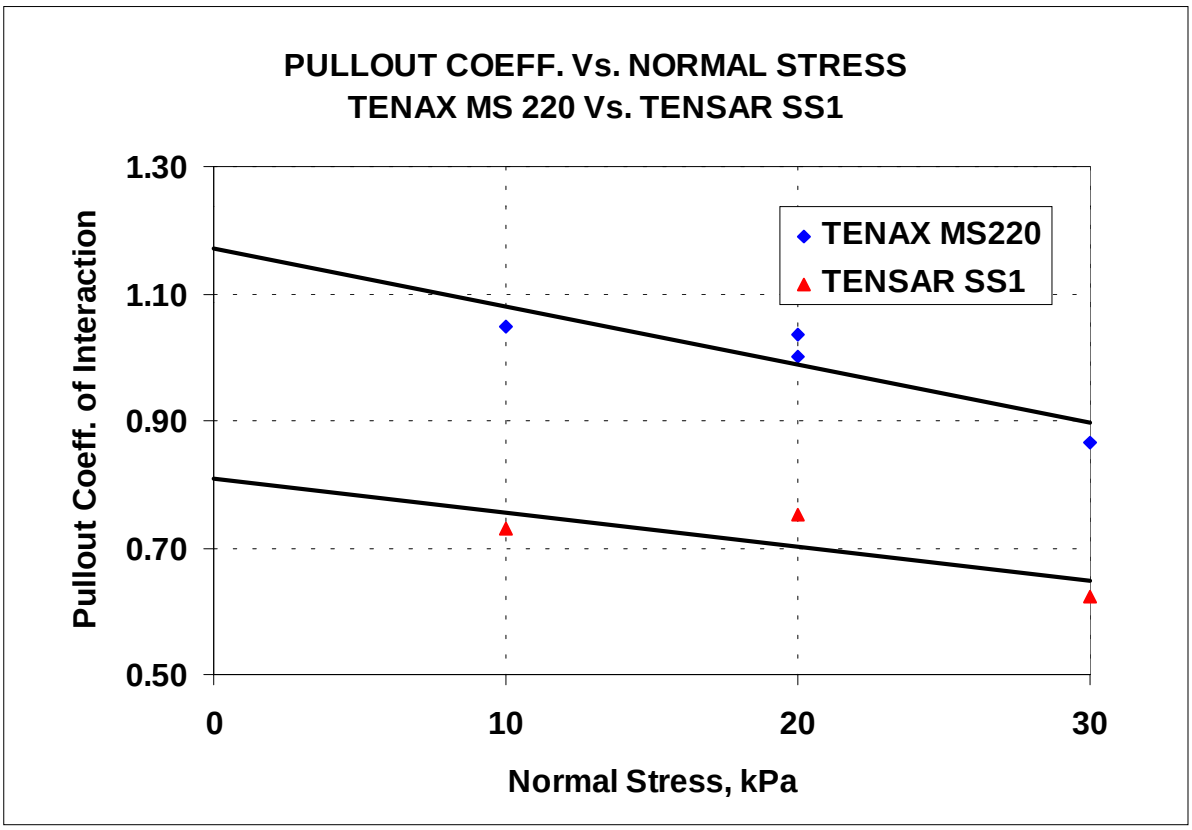

Tensar SS2 Vs. Sand EN 196:1
Pull-out Strength, kN/m
30
25
20
15
10
5
0
30 kPa
20 kPa
10 kPa
0
20
40
60
80
100
120
Displacement, mm
Test n.: PO018-19-26/97

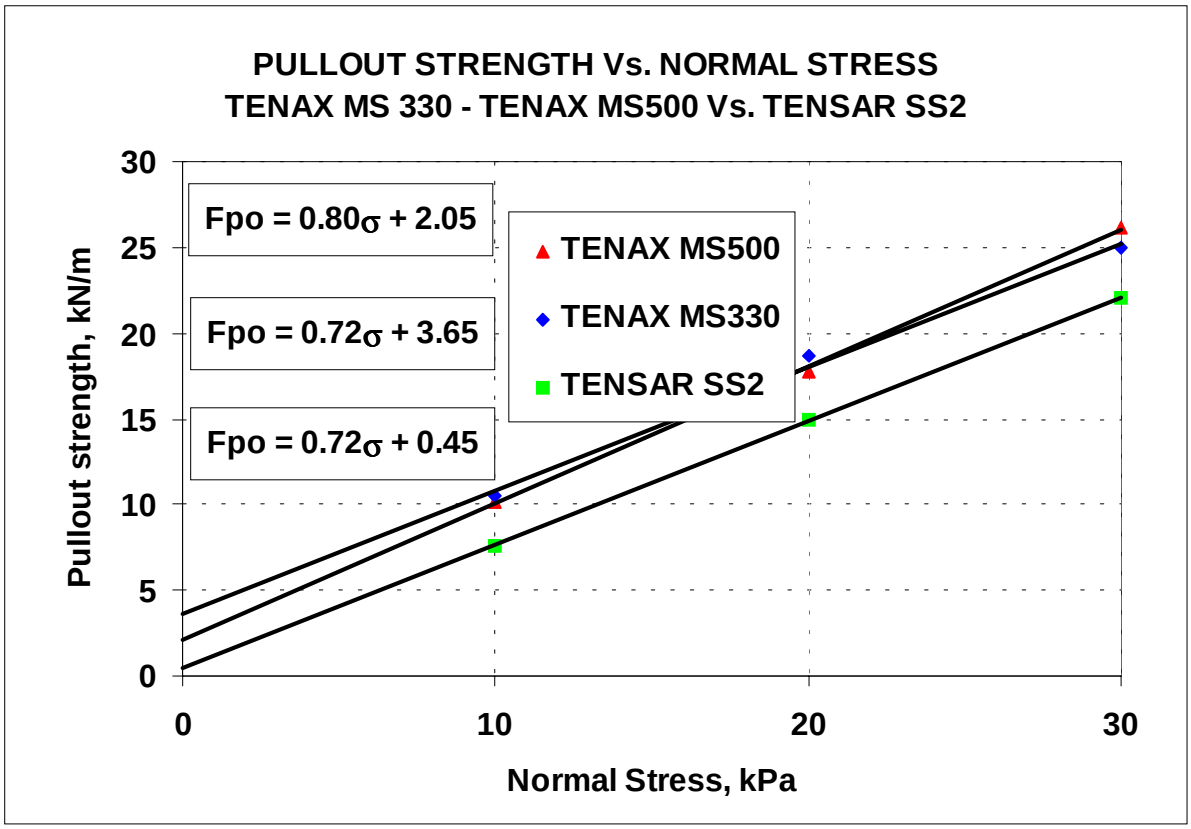

PULLOUT STRENGTH Vs. NORMAL STRESS
TENSAR SS2 Vs. SAND
Pullout Strength, kN/m
30
25
20
15
10
5
0
0
10
20
30
Normal Stress, kPa
y = 0.72x + 0.45

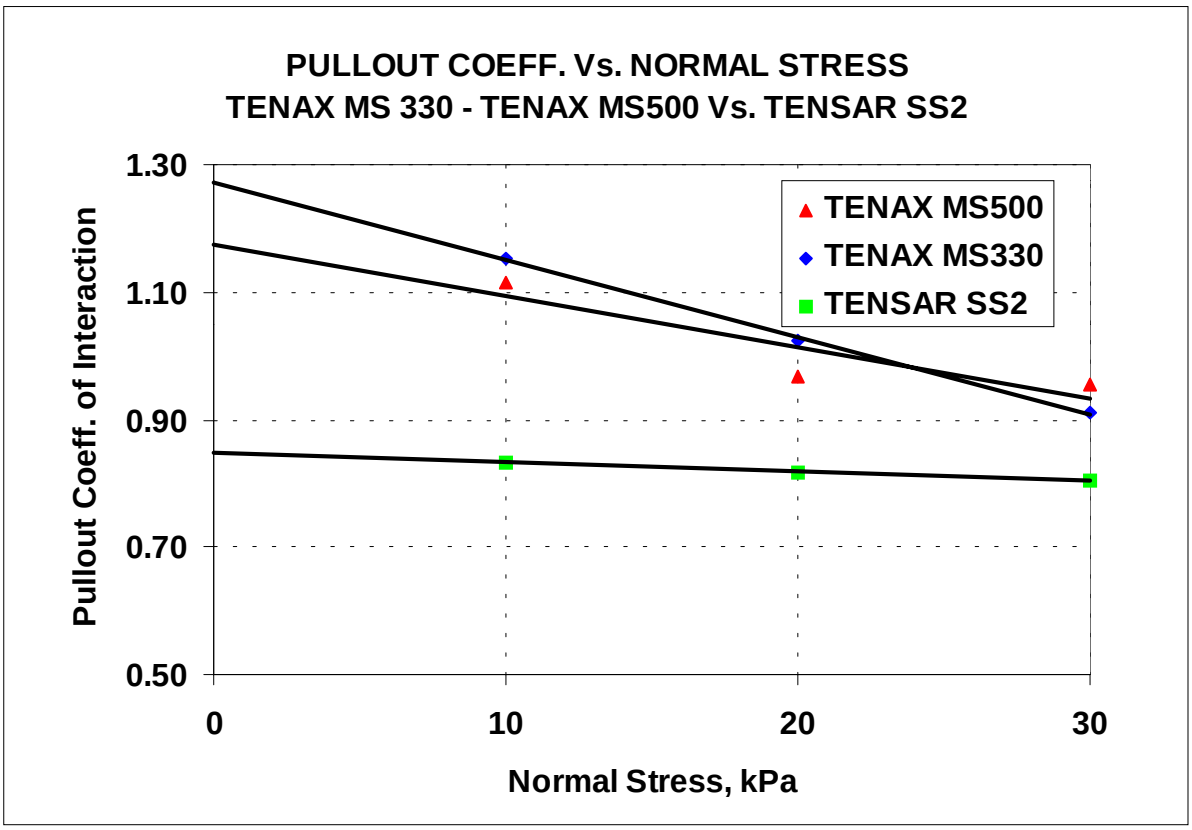

PULLOUT COEFF. Vs. NORMAL STRESS
TENSAR SS2 Vs. SAND
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
Normal Stress, kPa

ù


PULLOUT STRENGTH Vs. NORMAL STRESS
TENAX MS 220 Vs. TENSAR SS1
Pullout strength, kN/m
30
25
20
15
10
5
0
0
10
20
30
Normal Stress, kPa
TENAX MS220
TENSAR SS1
Fpo = 0.71σ + 3.48
Fpo = 0.52σ + 2.09


PULLOUT COEFF. Vs. NORMAL STRESS
TENAX MS 220 Vs. TENSAR SS1
Pullout Coeff. of Interaction
1.30
1.10
0.90
0.70
0.50
0
10
20
30
Normal Stress, kPa
TENAX MS220
TENSAR SS1


PULLOUT STRENGTH Vs. NORMAL STRESS
TENAX MS 330 - TENAX MS500 Vs. TENSAR SS2
Fpo = 0.80σ + 2.05
Fpo = 0.72σ + 3.65
Fpo = 0.72σ + 0.45
TENAX MS500
TENAX MS330
TENSAR SS2
Pullout strength, kN/m
Normal Stress, kPa
0
5
10
15
20
25
30


PULLOUT COEFF. Vs. NORMAL STRESS
TENAX MS 330 - TENAX MS500 Vs. TENSAR SS2
TENAX MS500
TENAX MS330
TENSAR SS2
Pullout Coeff. of Interaction
Normal Stress, kPa
0.50
0.70
0.90
1.10
1.30
0
10
20
30